Can we have A p-type point-contact high-purity germanium detector with an amorphous semiconductor surface?

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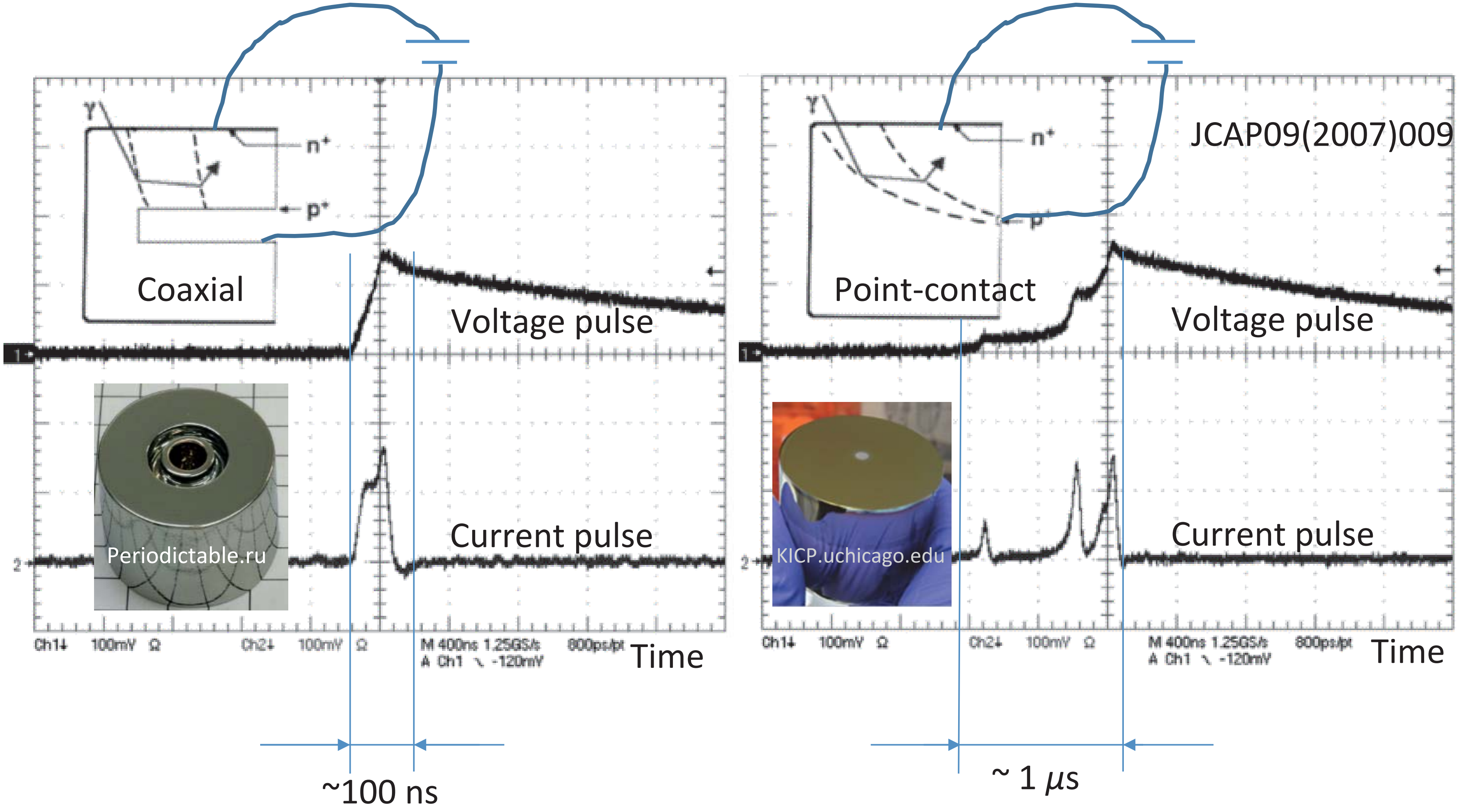
University of South Dakota

Symposium on Germanium Detectors
Ringberg, October, 2015

Why point-contact

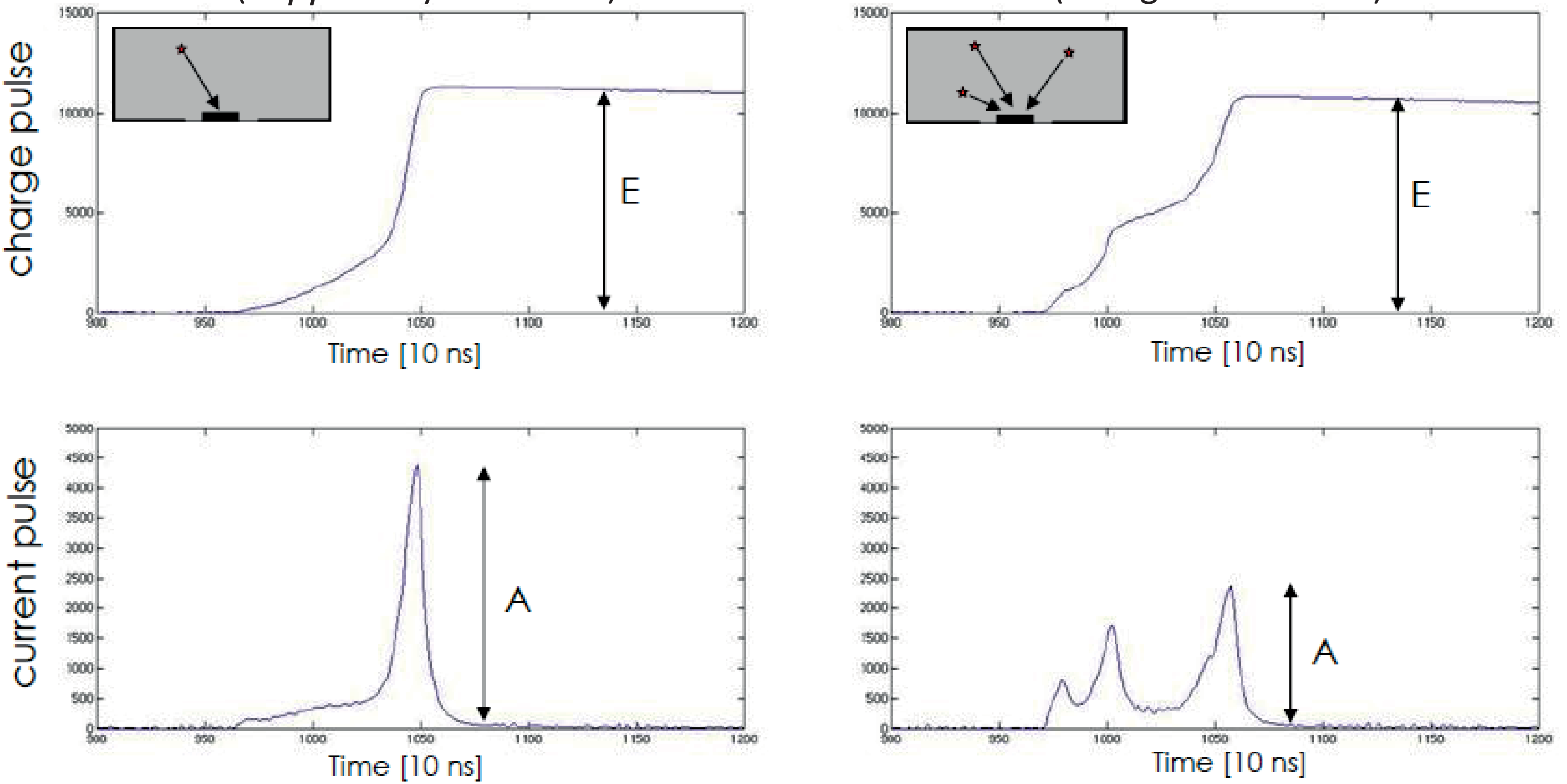


Why point-contact in $0\nu\beta\beta$ experiments

D. Budjas, Ge-workshop, Beijing, 2011

single-site event (SSE)
($0\nu\beta\beta$-decay candidate)

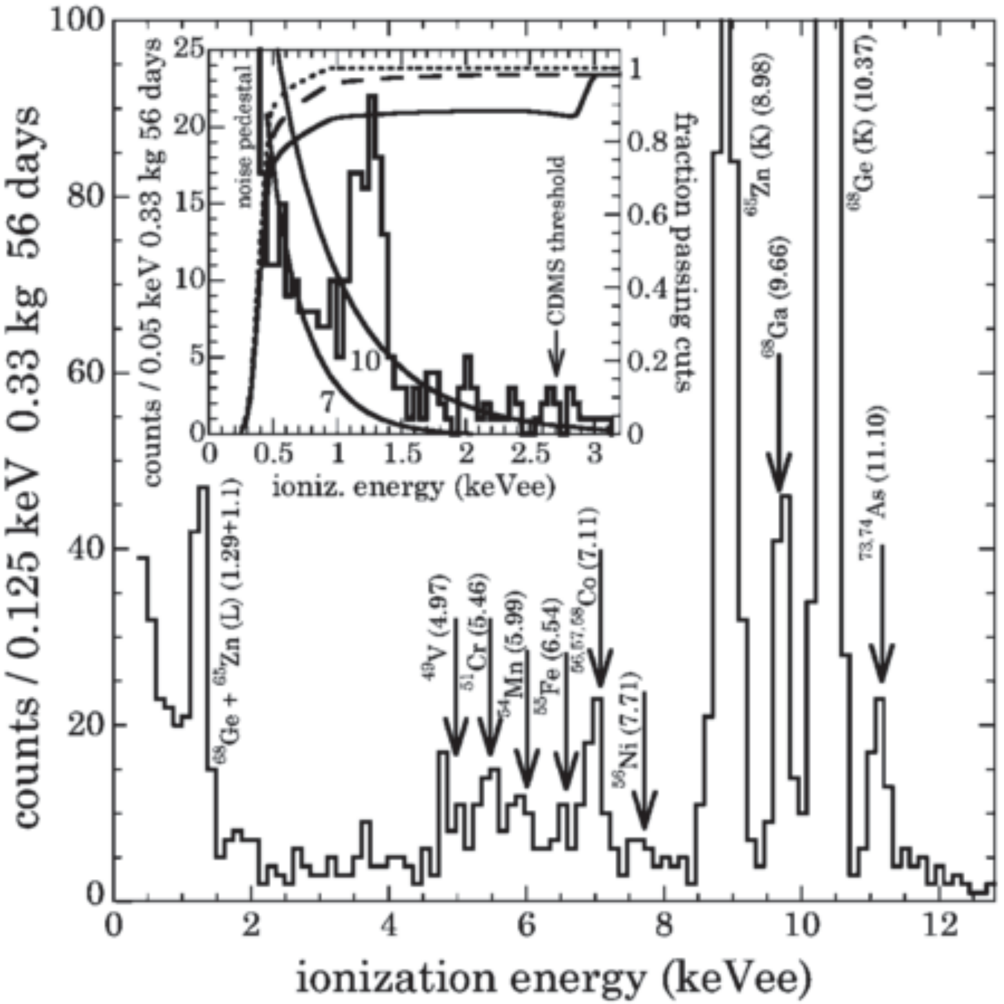
multi-site event (MSE)
(Background events)



Why point-contact in dark matter experiments

- Point-contact
  - →Low capacitance
    - →Low noise
      - →Low energy threshold

CoGeNT, PRL, 2011

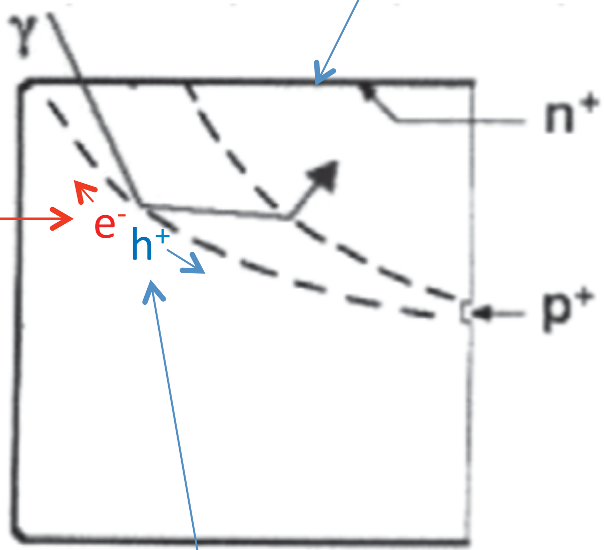


Why p-type

Easier to be trapped,
collected by surface,
drift a short distance

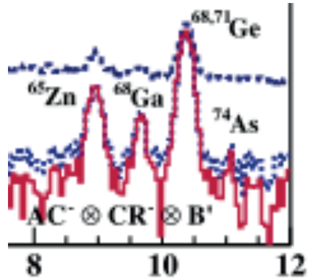
Li-diffused outer surface

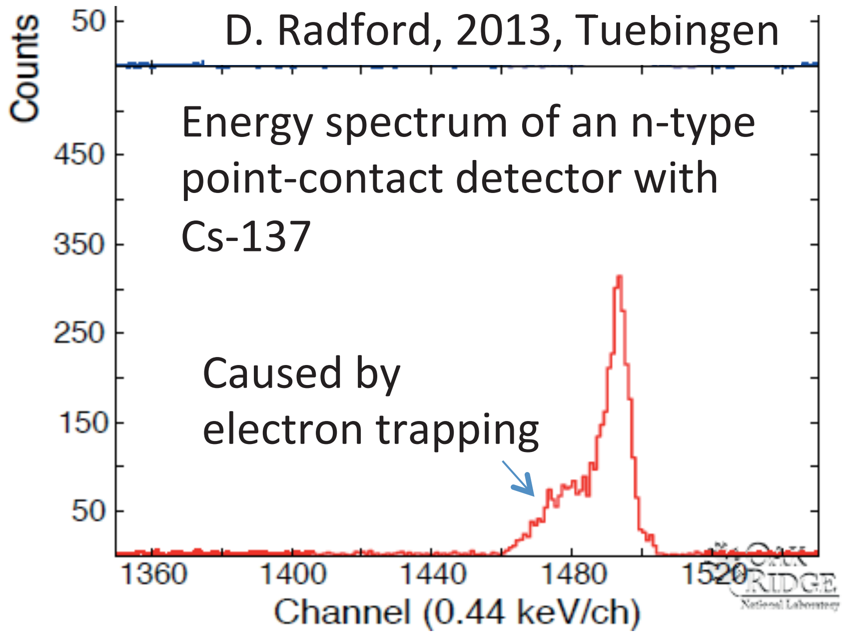
- Thick! ~ 1 mm
  - ⟶ Robust!
  - ⟶ Block α!



Harder to be trapped,
collected by point-contact,
drift a long distance

Energy spectrum of a p-type point contact from TEXONO



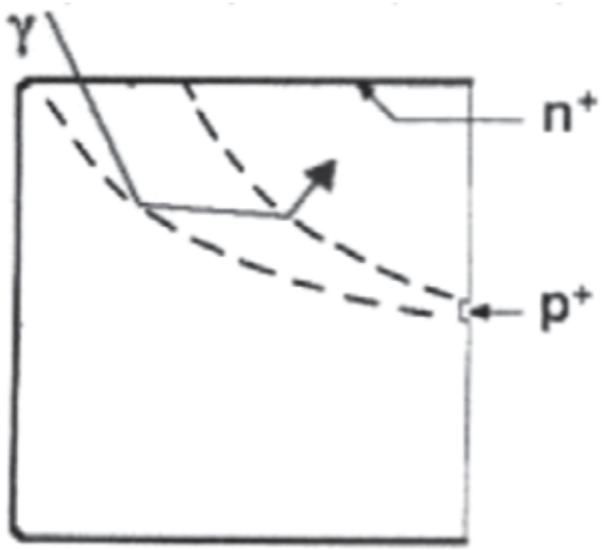


Energy spectrum of an n-type point-contact detector with Cs-137

Caused by electron trapping

Long drift length and weak field in a point-contact configuration makes the effect of electron trapping prominent!

Why bother



3 disadvantages of

Li-diffused outer surface

1. Hard to segment!
2. Waste of expensive Ge!!
3. It is not completely dead!!!

Hard to segment

- 1 mm thick
  - ⟶ hard to segment
- What if we do it anyway
  - ⟶ position sensitivity
  - ⟶ waste material
  - ⟶ distort electric field
  - ⟶ loss charges on boundary

P-type segmented detector
Ge detector development group
Max-Planck-Institut fuer Physik

Not cheap

Especially for 0νββ experiments!

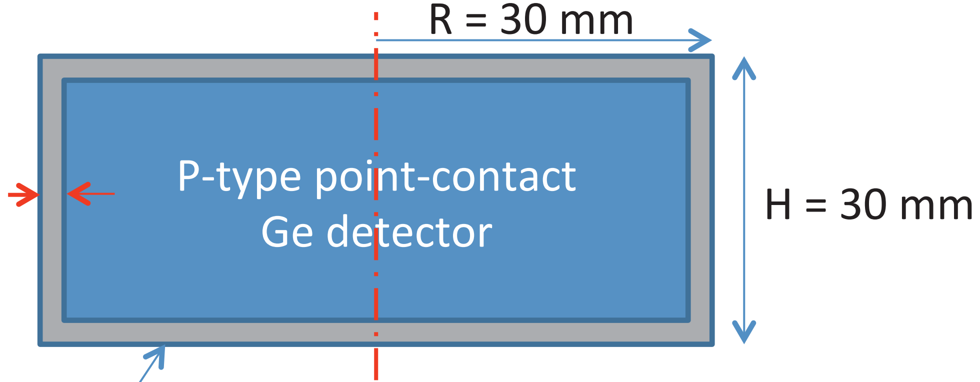
Depends a lot on detector geometry, may vary from 7% ~ 30%

Volume of the completely and partially dead surface

$$1-\frac{2\pi(R-\delta_1-\delta_2)(H-\delta_1-\delta_2)(2\pi(R-\delta_1-\delta_2)^2}{(2\pi RH+2\pi R^2)}$$

Volume of the whole detector

δ_1=1 mm (completely dead surface)
δ_2=1 mm (partially dead layer)
Ref. CoGeNT 2011 PRL



In order to block α, we have to cover the entire surface with Li-diffused layer

Surface contamination

- A ~1 mm transient layer below Li-diffused surface (CoGeNT, 2011, PRL)
  - Not completely dead
    - You can collect some charge carriers, but not all!
      - High energy events become low energy
        - » Create dark matter signal?!
      - Low energy events fall below threshold
        - » Lose ¼ dark matter signal?!

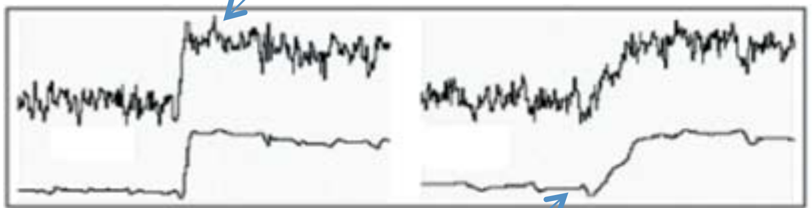
Rise time as rescue

Which does not work at low energy ☹

It takes time for charge carriers to diffuse out of the transient layer -> slow pulse!

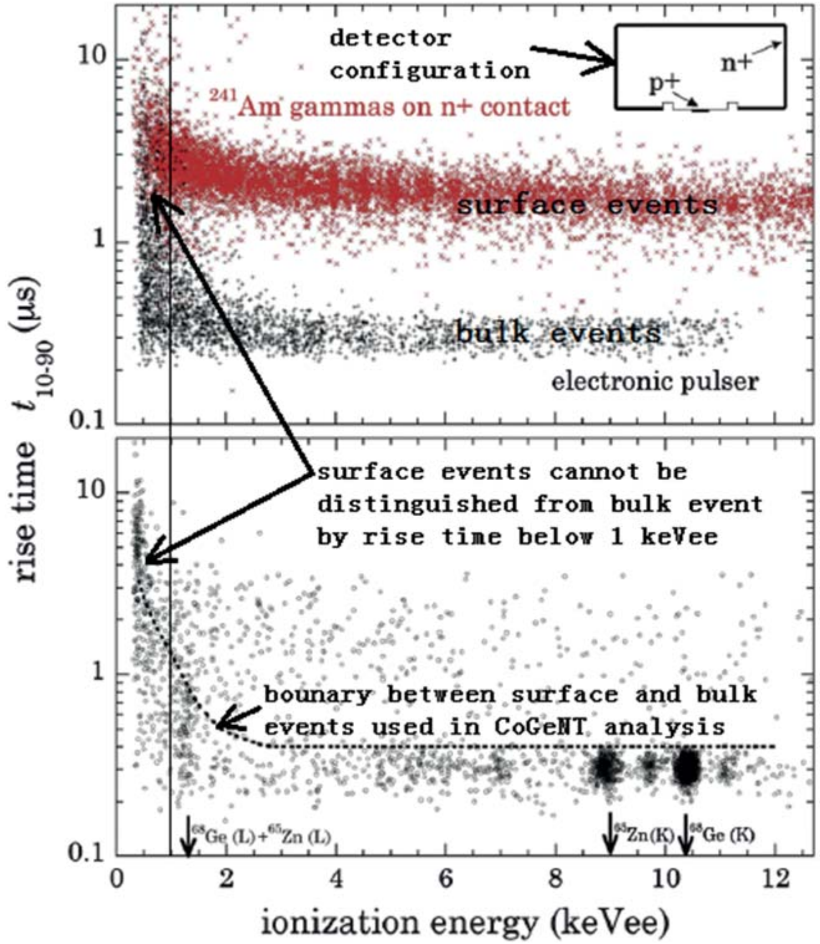
Ref. P. S. Finnerty's PhD thesis, University of North Carolina at Chapel Hill, 2013.

Fast pulses assumed to be from bulk



Slow pulses assumed to be from surface

CoGeNT, 2011, PRL



One-for-all solution

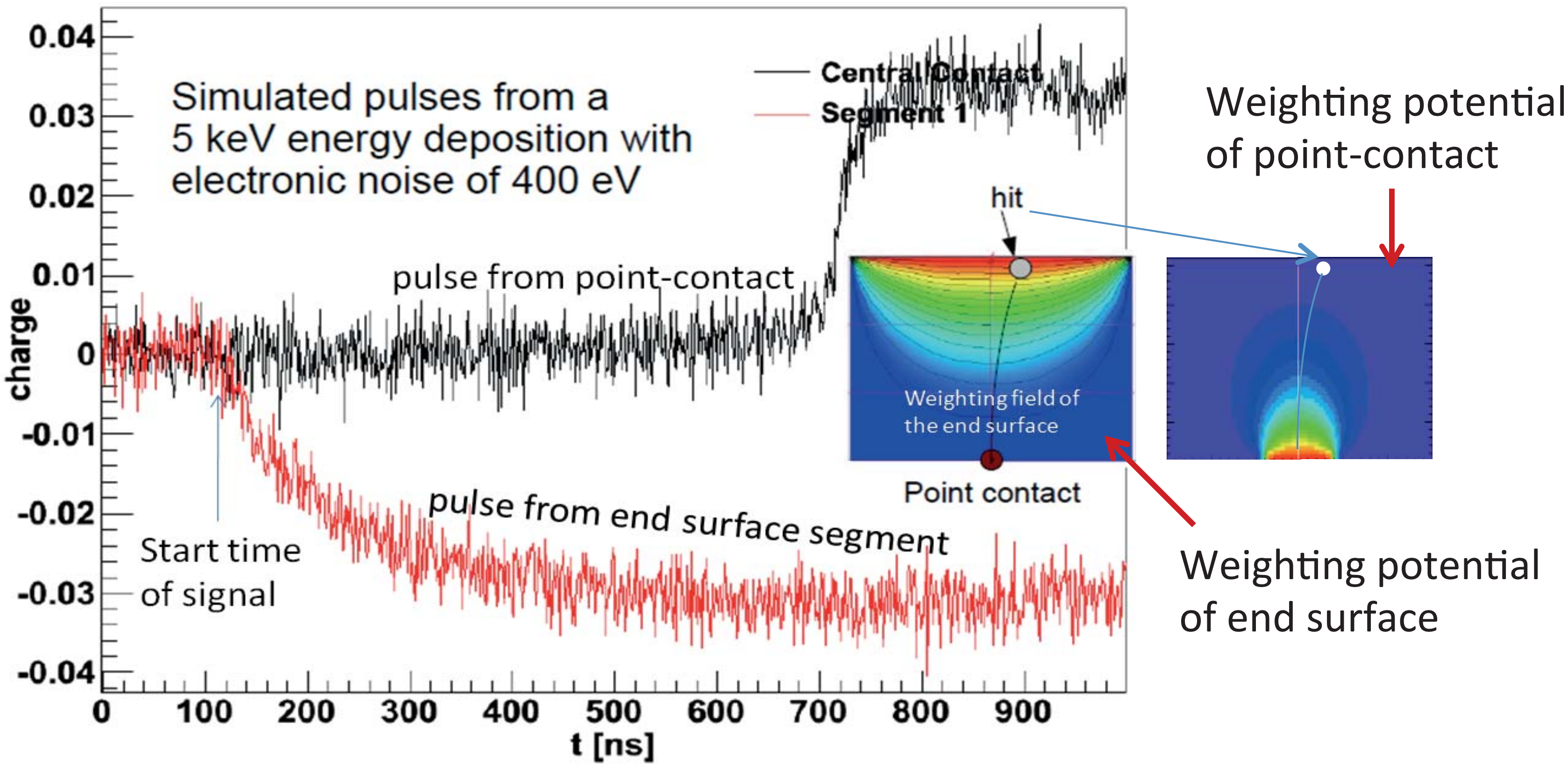
- 1 μm thick amorphous Ge surface
  - No waste of Ge ☺
  - Easy to segment ☺
  - No partially dead layer ☺

Surface becomes sensitive to low energy radiations

Surface events can be easily identified with
- fully deposited energies and
- rise times of electric pulses

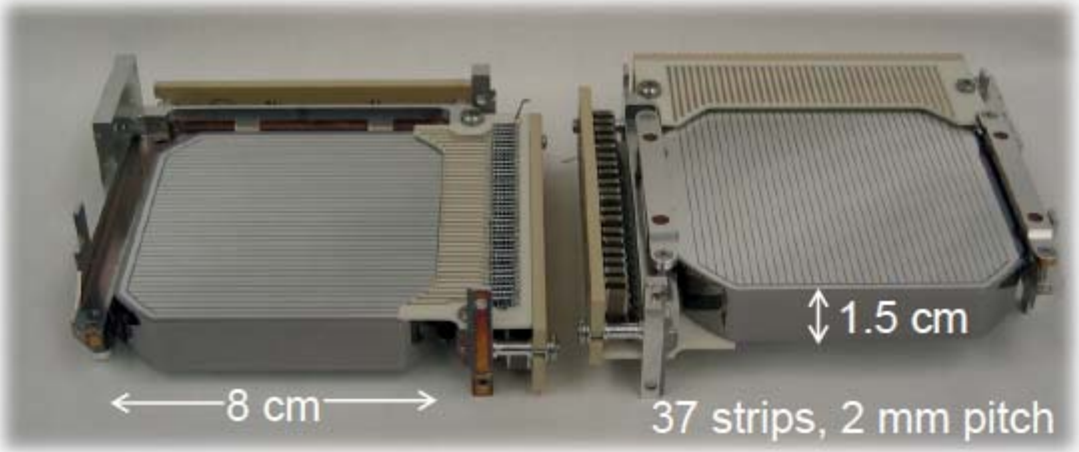
Bonus from segmentation

Rise time of a low energy event can be determined more precisely with the help of surface segment contact!



Technical feasibility

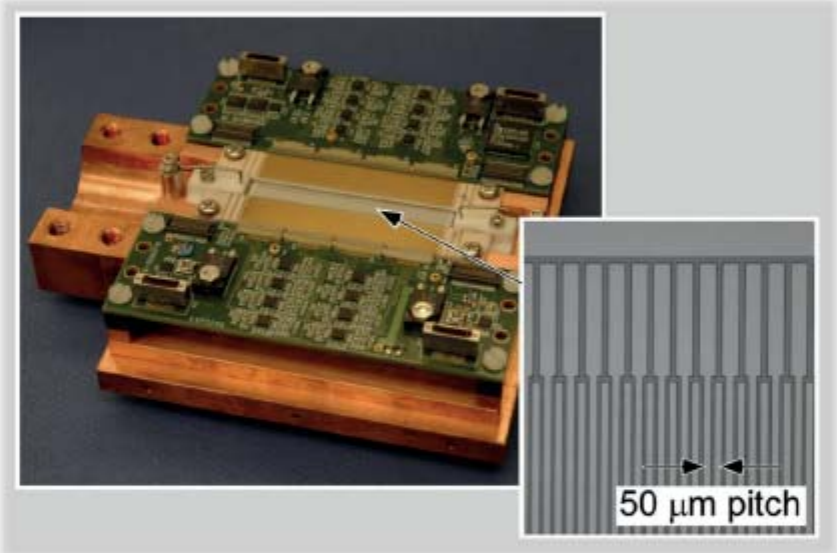
M. Amman, Ge Workshop 2014, USD

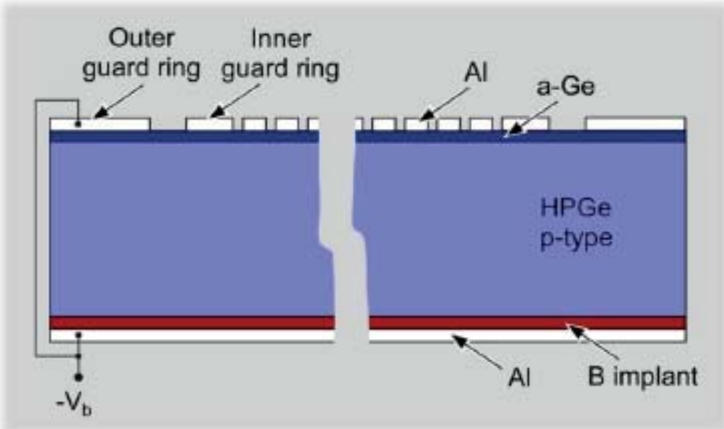


Developed for gamma-ray astronomy, Nuclear Compton Telescope (NCT)
S. Boggs, et al., SSL UCB

a-Ge/HPGe/a-Si
< 1pA / strip @ ~80 K

a-Ge/HPGe/a-Ge
< 10pA / strip @ ~80 K

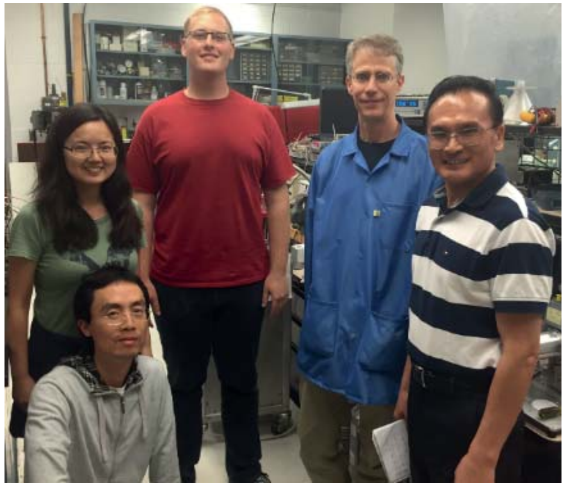




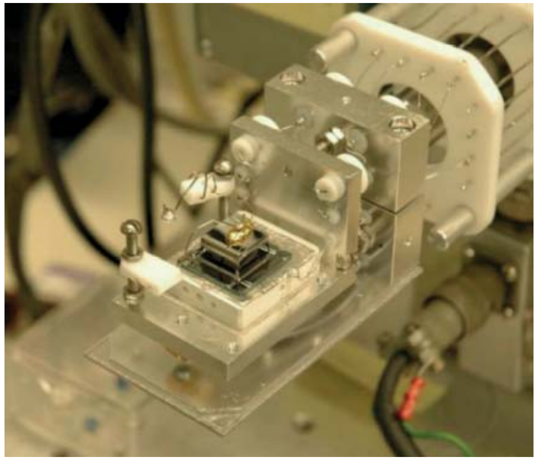
1024 strips, 50 μm pitch, 5 mm length
1 mm thick detector

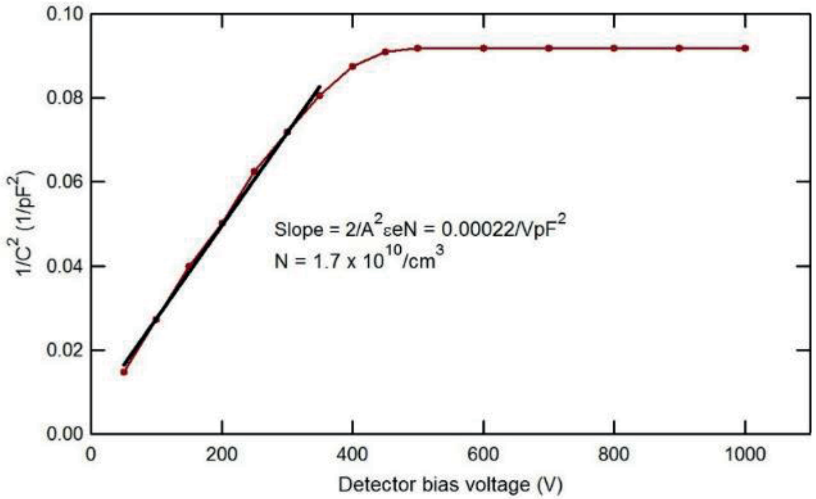
Collaborate with LBNL

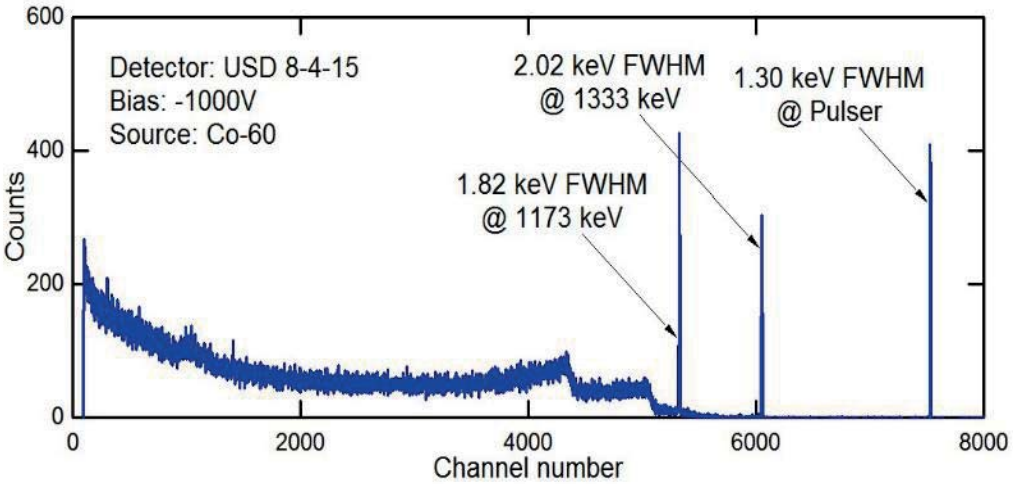
A week-long visit at LBNL, August, 2015



- Ge crystal, USD
- A-Ge surface, LBNL

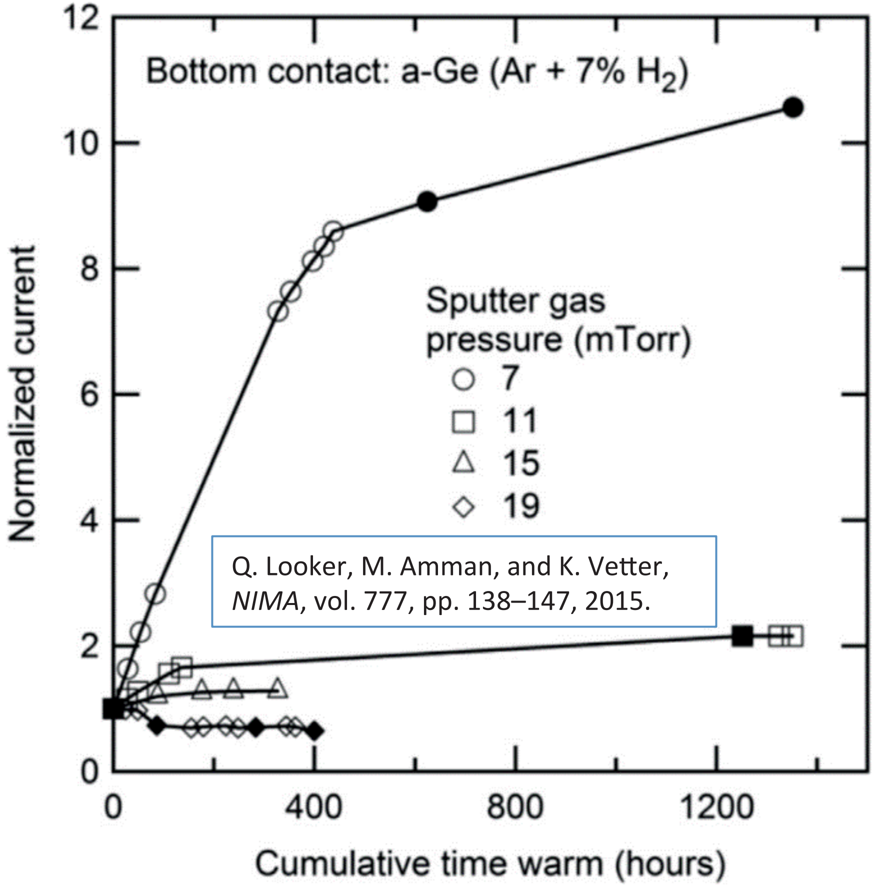






Challenge

Leakage current of small cubic detector is already under control!



Q. Looker, M. Amman, and K. Vetter, *NIMA*, vol. 777, pp. 138–147, 2015.

Mark has tried a-Ge on PPC, leakage current was too high

↓

Problem was the geometry: cylindrical shape was hard to handle in sputtering and evaporation processes

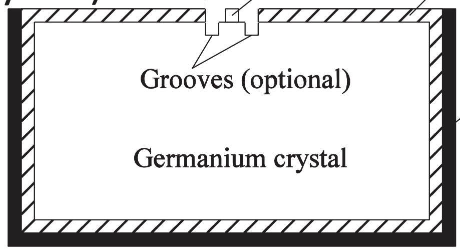
↓

Handling methods have to be carefully designed.

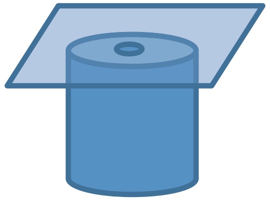
Several ideas of handling complicated geometries

Small cubic PPC with wings
(1 point-contact to start with)

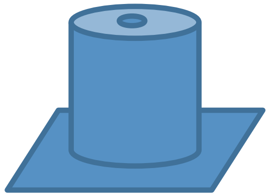
Groove around point-contact
(the only place where handling structure is attached to the crystal)



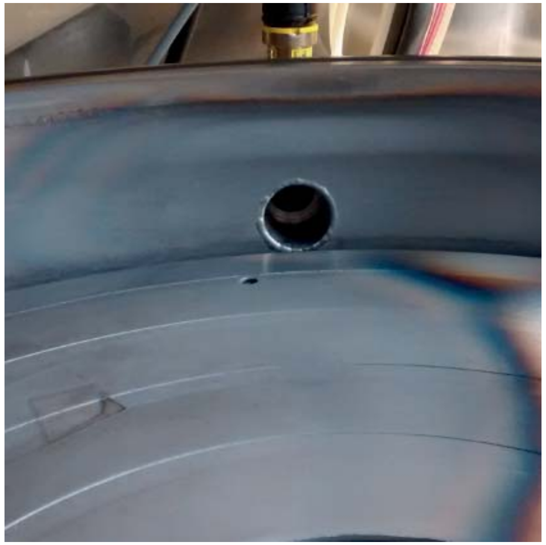
Handling wing remained on top surface



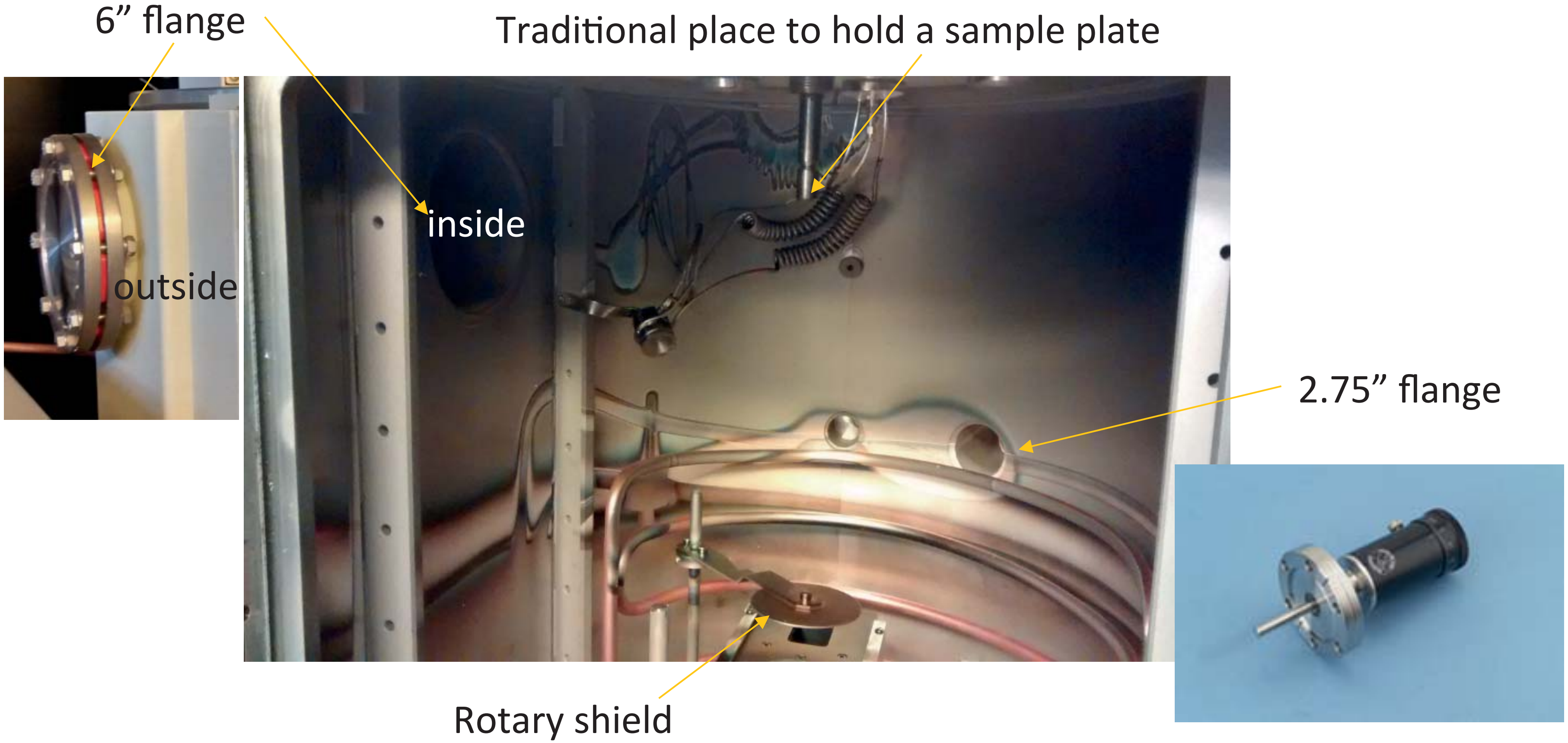
Handling wing remained on bottom surface
(side surface and bottom surface become separated contacts naturally)



Sputtering machine modification



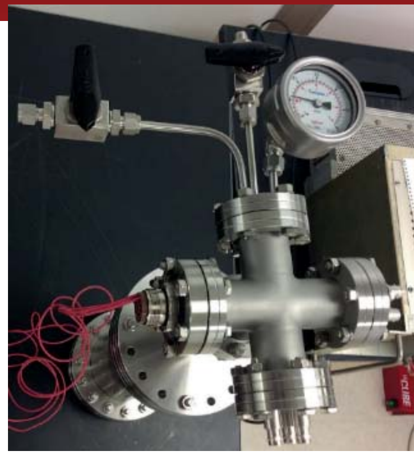
E-beam evaporation machine modification



Test cryostats (see Mitchell's talk for details)

Dip-in design

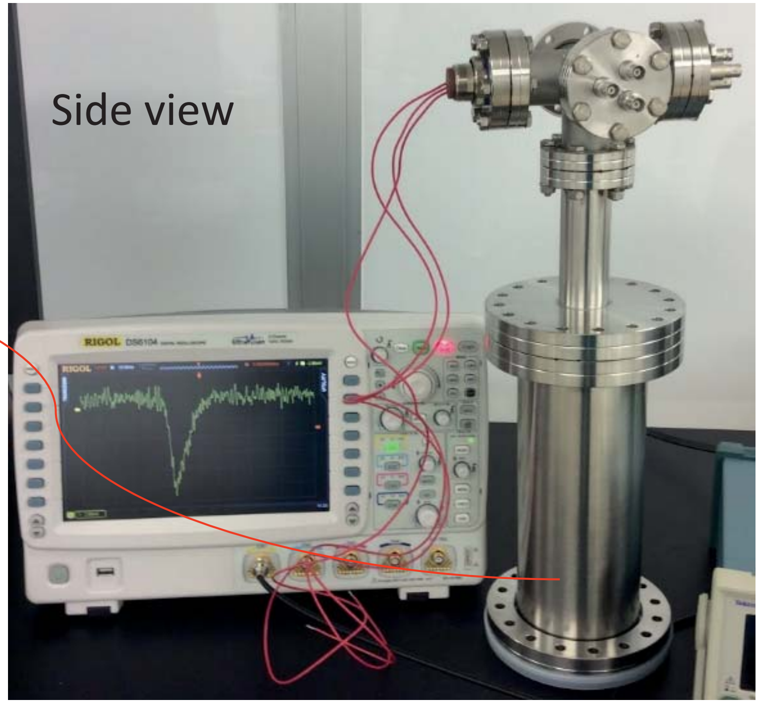
Top view of
feed-throughs:



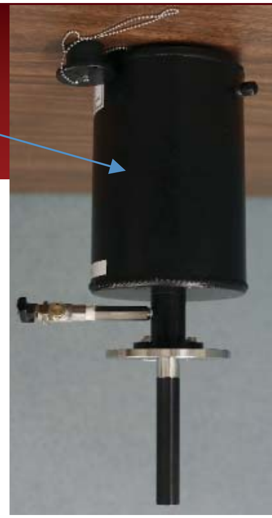
LN_2 open dewar

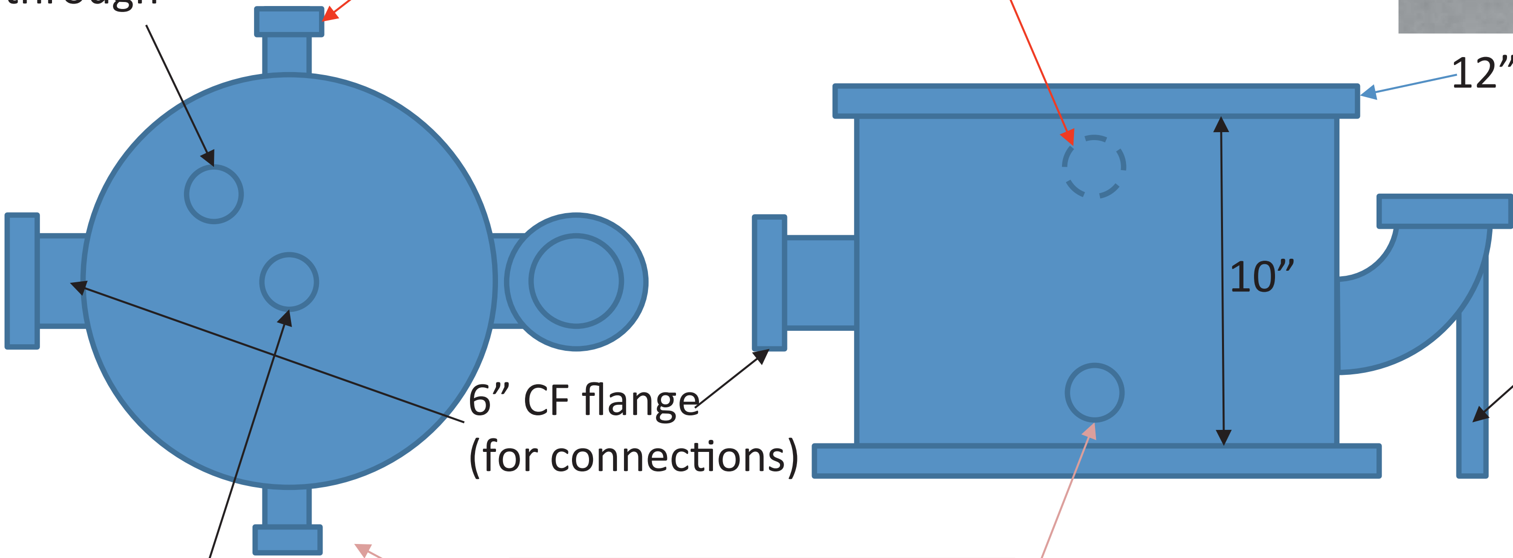
Dip in to
cool
down

Side view



Test cryostat for surface scanning





Summary

P-type point-contact is great,
We can make it better.

Thank you!